Methods for Modeling Impact-Induced Reactivity Changes in Space Reactors

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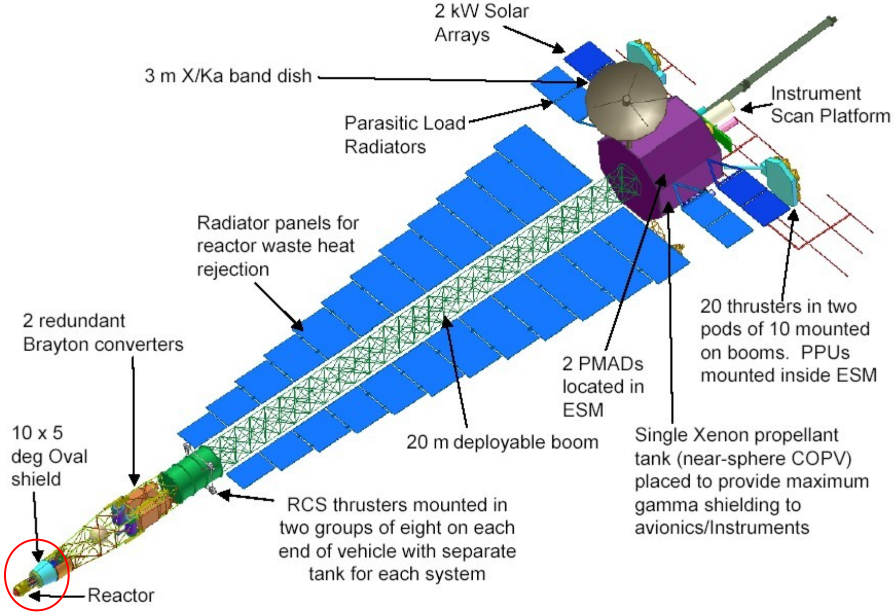
Prometheus (JIMO) Spaceship (2004)

Courtesy NASA



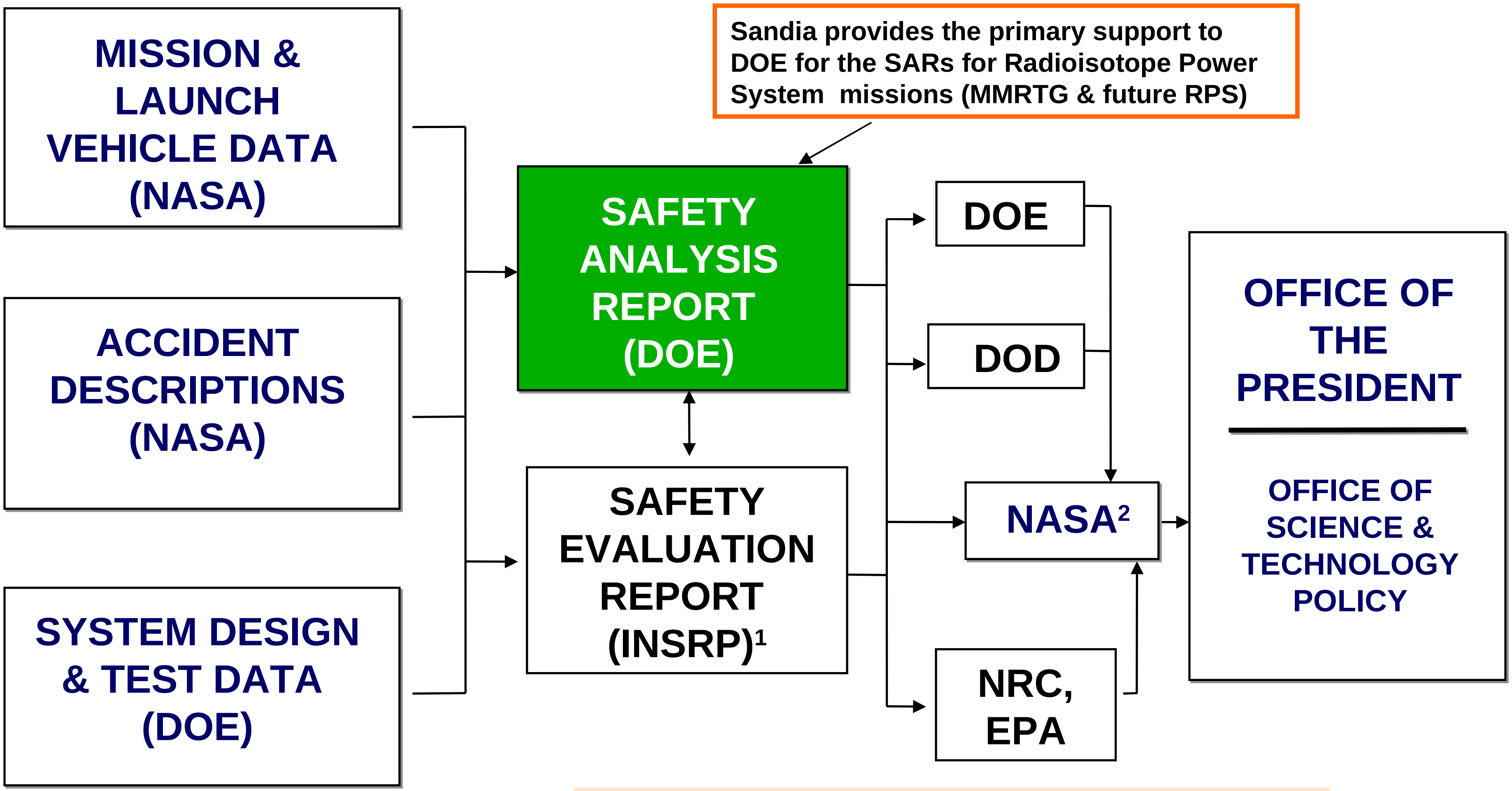
Launch Failures Can Occur

Delta 241 Jan 27, 1997

Atlas Fallback

Delta 241

A Process Exists for Launch Approval of Radiological Payloads



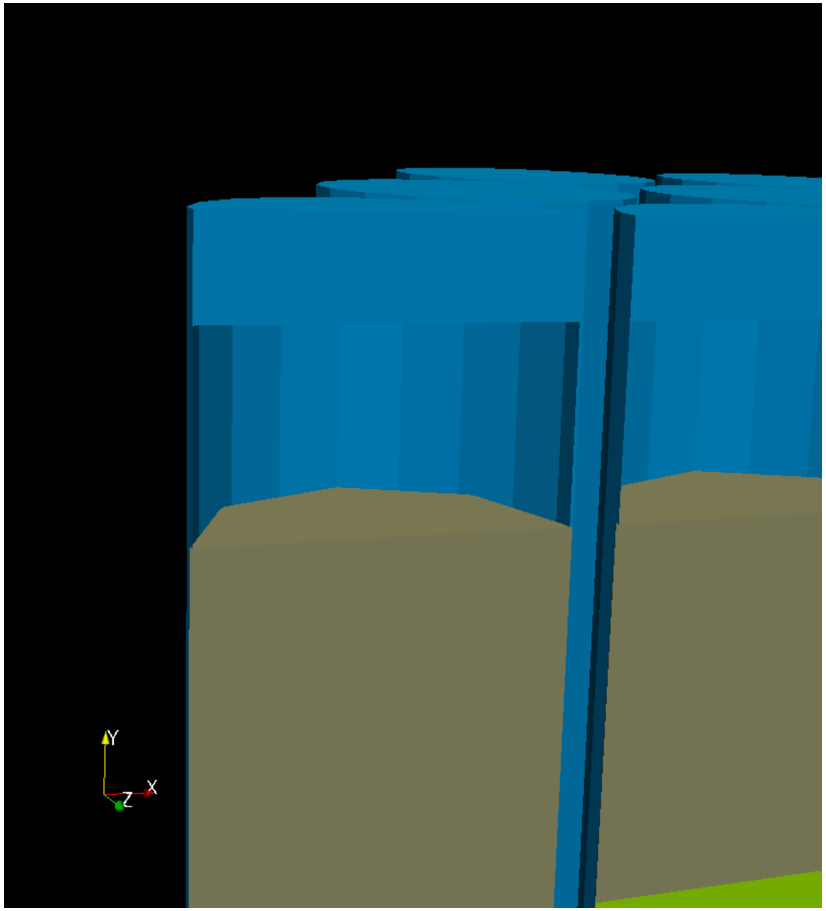
[1] Interagency Nuclear Safety Review Panel
[2] Responsible mission agency makes launch recommendation

Analysis Workflow

- CUBIT used to generate mesh
- Continuum mechanics codes used to simulate impact and obtain deformed geometry (PRONTO3D/PRESTO)
- DAGMC reads pre-deformed geometry to define ray tracing geometry
- DAGMC then reads post-deformed geometry and updates the location of the nodes in the mesh
- DAG-MCNP5 performs Monte Carlo radiation transport/criticality calculation

Challenge: Complement Volumes

- Complement volumes are the non-solid portions that are not explicitly represented in the solid model representation
- DAGMC currently recognizes these all as one disjointed region with the same material properties
- Developments are underway at UW-Madison to add the capability of recognizing multiple regions, allowing the user to distinguish between the coolant, gas plenums, etc.



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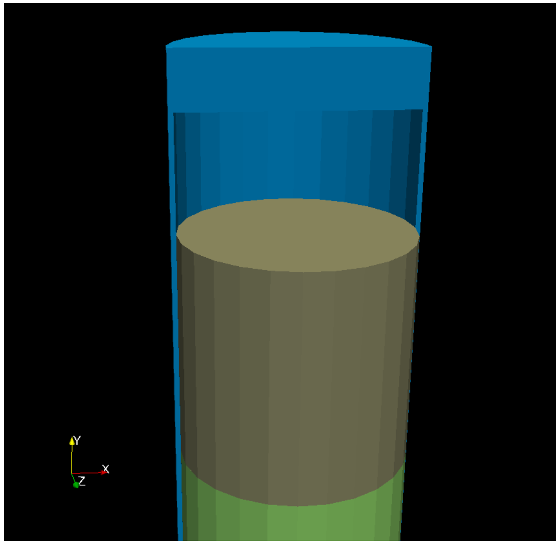
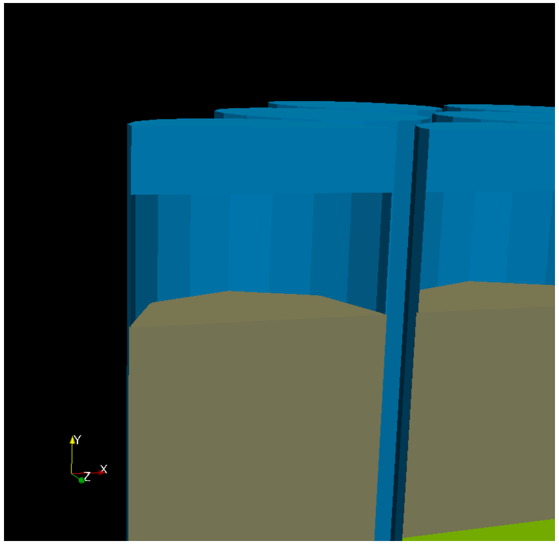
Challenge: Shell Elements

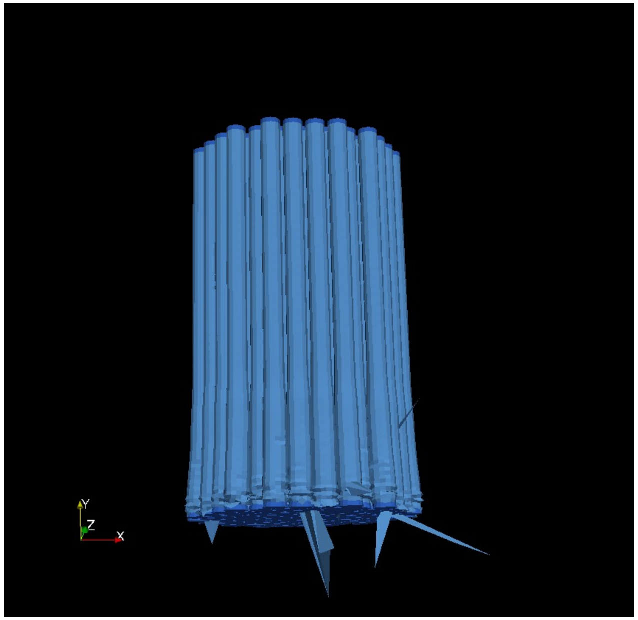
- Shell elements are used in the impact code to simulate very thin materials, such as the fuel clad
- They have no volume, but do have mass and stiffness
- DAGMC does not currently know how to treat these
- Shells can be manually removed prior to running DAG-MCNP5, but we are working on a way to deal with them automatically
- Would like to use the surface of the shell element to define complement volumes

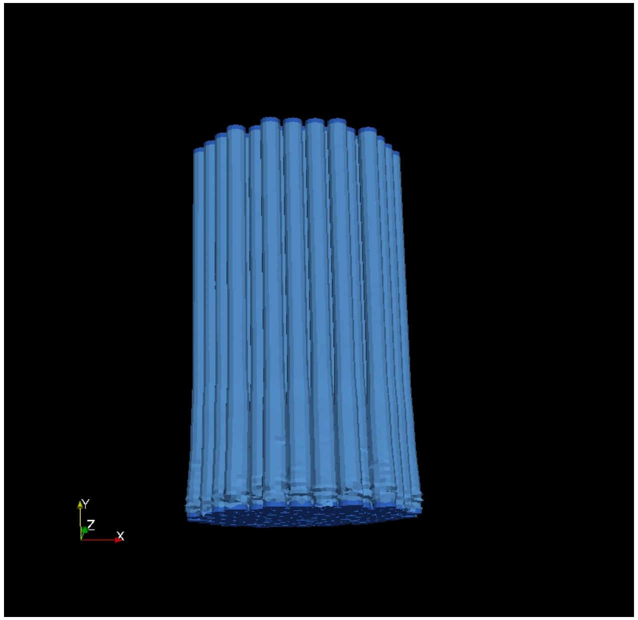




Challenge: Element Death

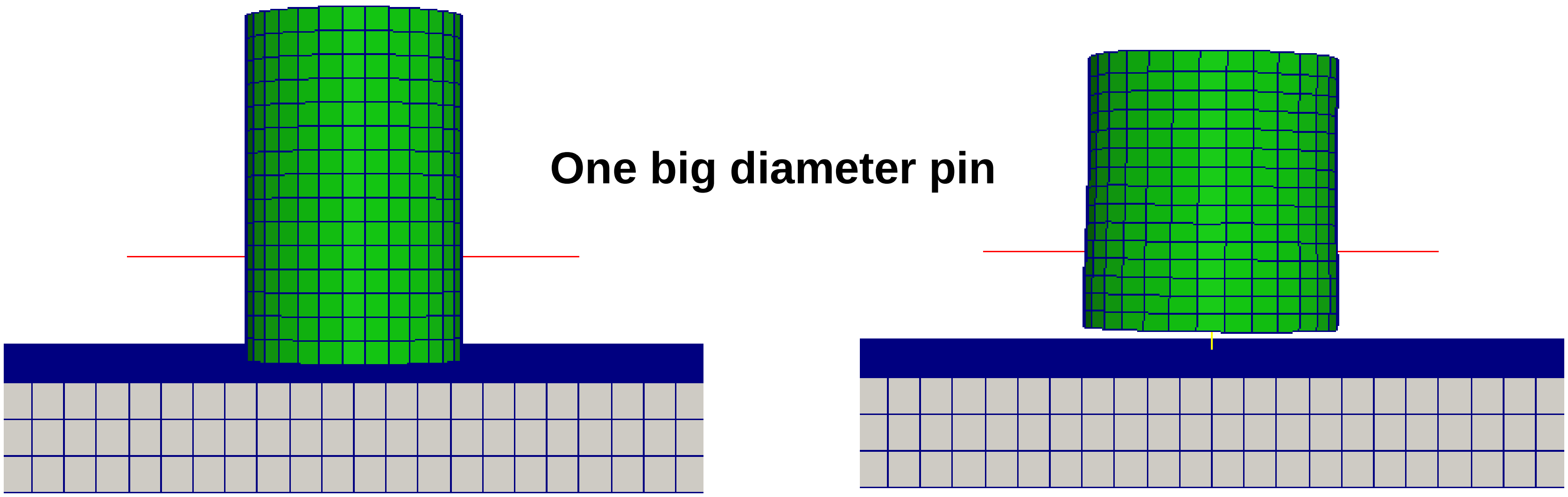
- Elements that have experienced an excessive amount of deformation in the impact calculation are sometimes “killed”, where the stiffness is set to 0
- Nodes of elements with 0 stiffness can simply move off to infinity, creating very large artificial volumes
- Portions of the material “disappearing” is non-physical and development is required for DAGMC to deal with this





Simple test-geometry impact and reactivity

- One large-diameter fuel pin used for proof of concept
- Demonstrated entire process
  - Geometry → meshed → impacted → read with DAGMC → reactivity using DAG-MCNP5
- Discovered that the fuel model* resulted in a decrease in fuel density
- Needed to adjust density in criticality code to conserve fuel mass
- Results for k-eff: Undeformed = 0.988, Deformed = 1.030, Deformed (density adjusted): 1.007

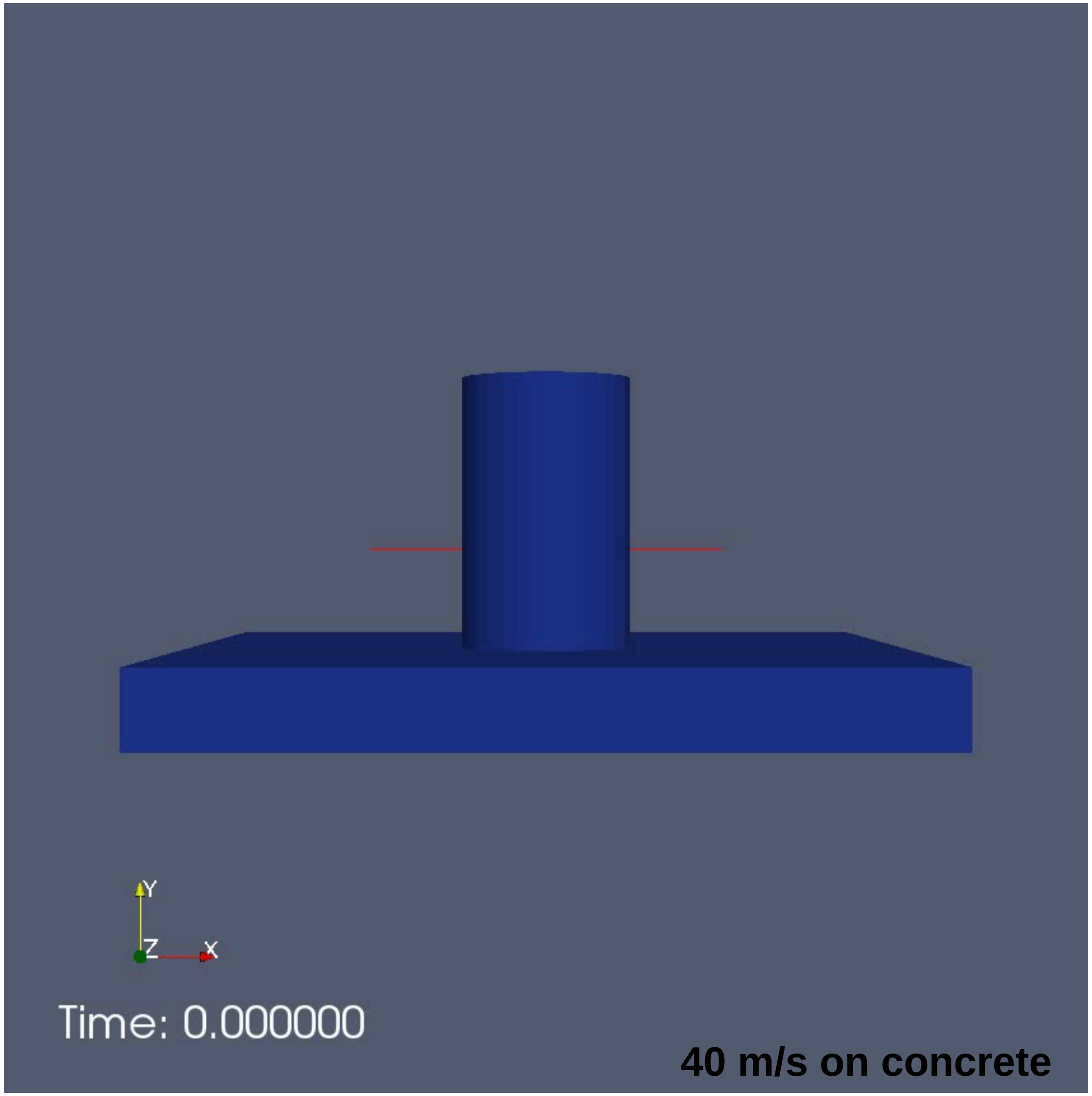


a) undeformed

b) deformed (40 m/s impact)

*Pronto3D "soil in foam" model validated in RTG impact tests for PuO_2 and UO_2

Impact of Large-Diameter Pin

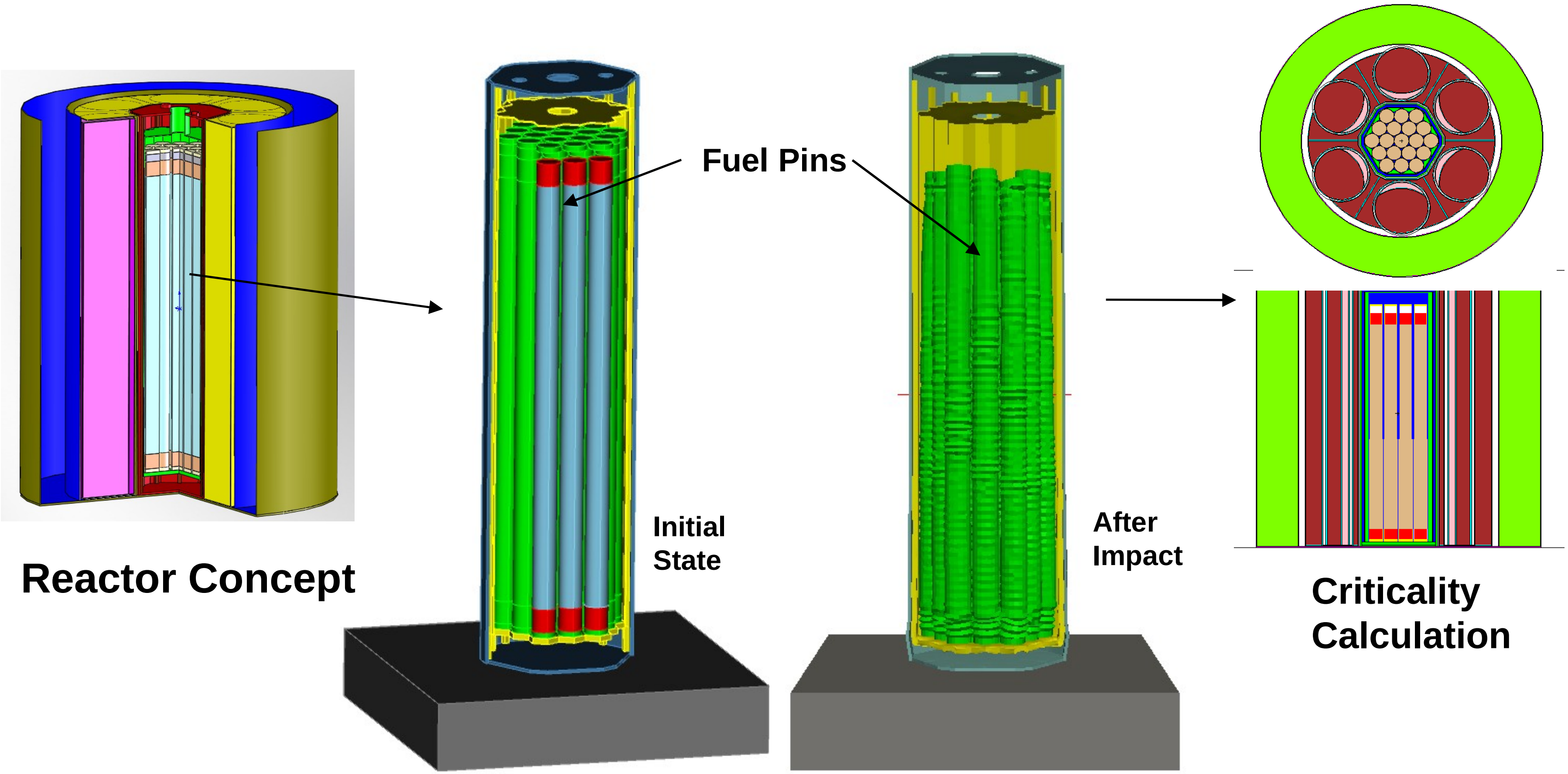


- **Peak compression is for a few milliseconds**
- **Rebound configuration is similar to peak compression**

Challenge: Non-uniform Density Changes

- **Deformation causes non-uniform changes in material density**
- **In single large-diameter pin test**
  - **9% increase in volume/decrease in density**
    - **~0% in top mesh elements**
    - **>9% in bottom mesh elements**
- **Need to characterize variation in density change in realistic reactor geometries**
  - **Narrow distribution of volume change permits uniform density adjustment**
  - **Wide distribution of volume change requires high-fidelity ray-tracing**

19-Pin Sample Reactor Impact



40 m/s (90 mph) impact on concrete

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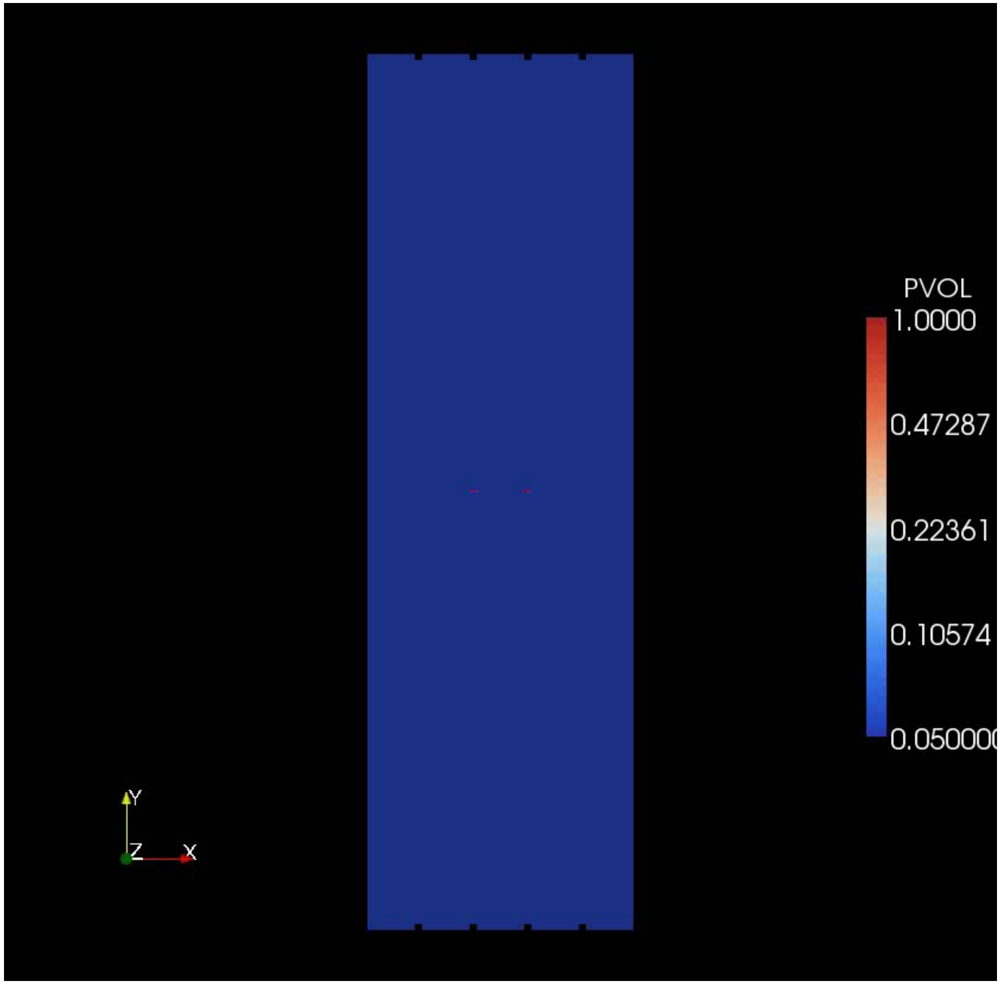
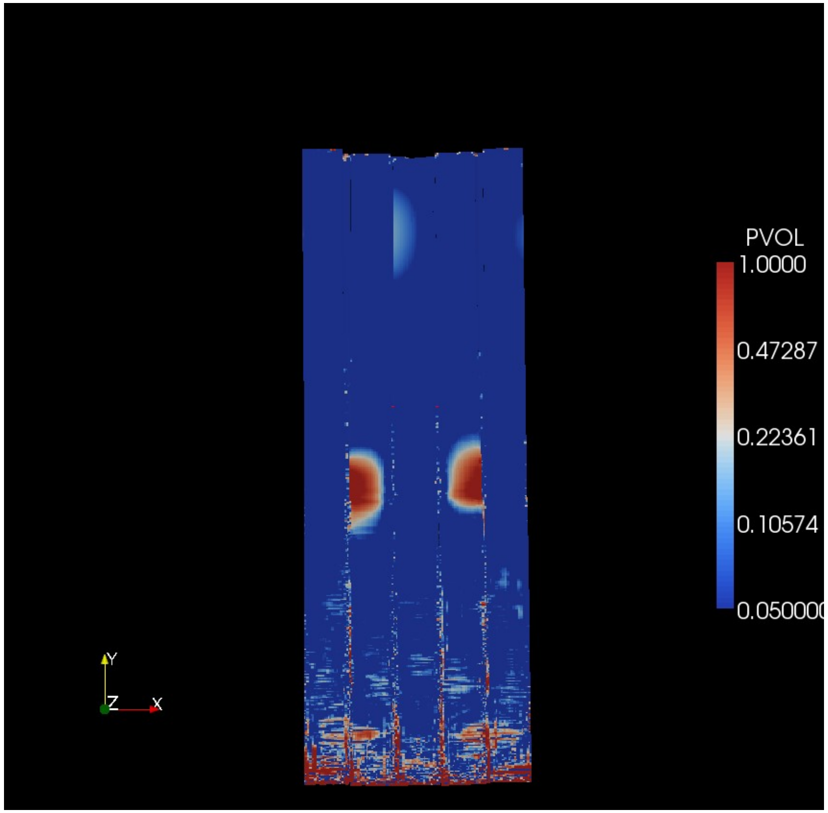
Non-uniform Density Change in 19-Pin Core





Scale represents percent change in volume for that mesh element

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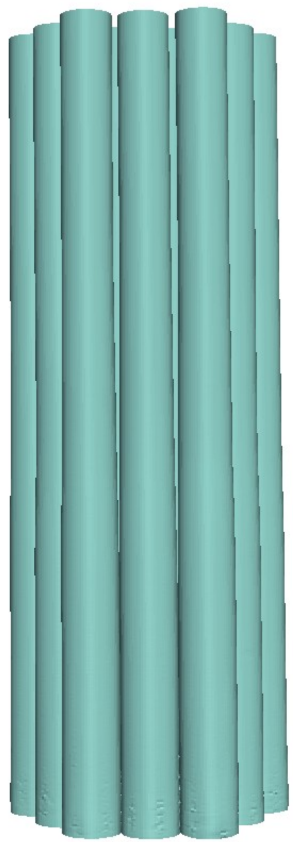
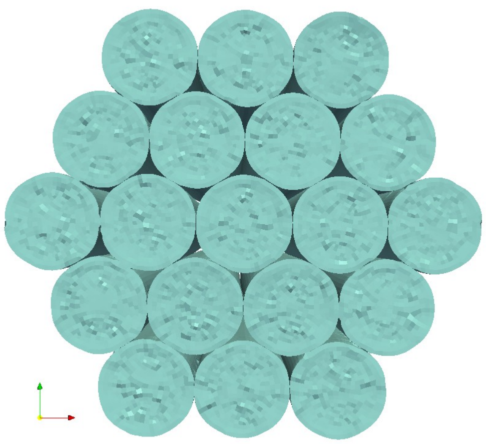
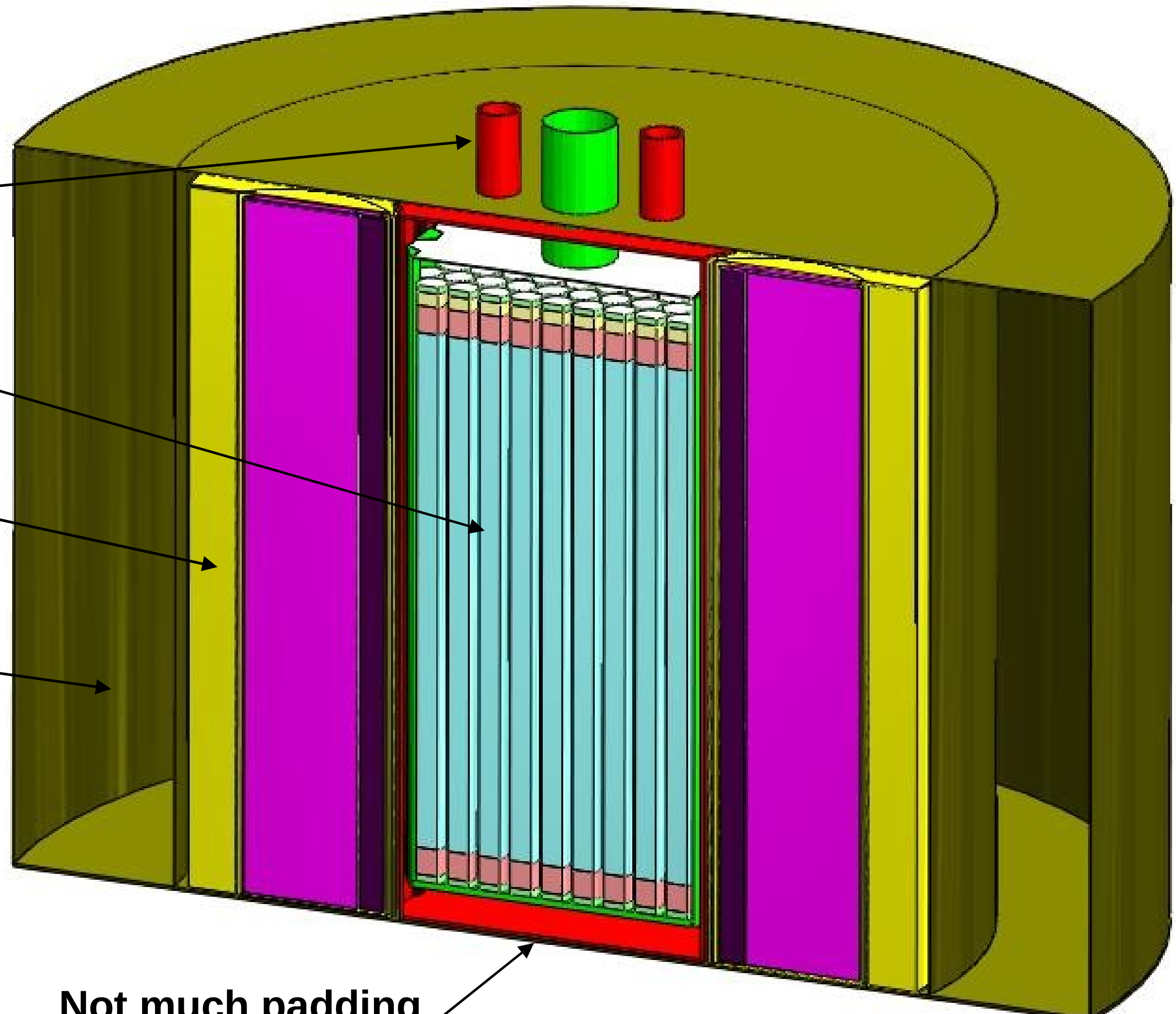
19-Pin Sub-Scale Reactor Results

- **All the pins bulge and touch in the lower half of the core**





85-Pin Full-Scale Space Reactor



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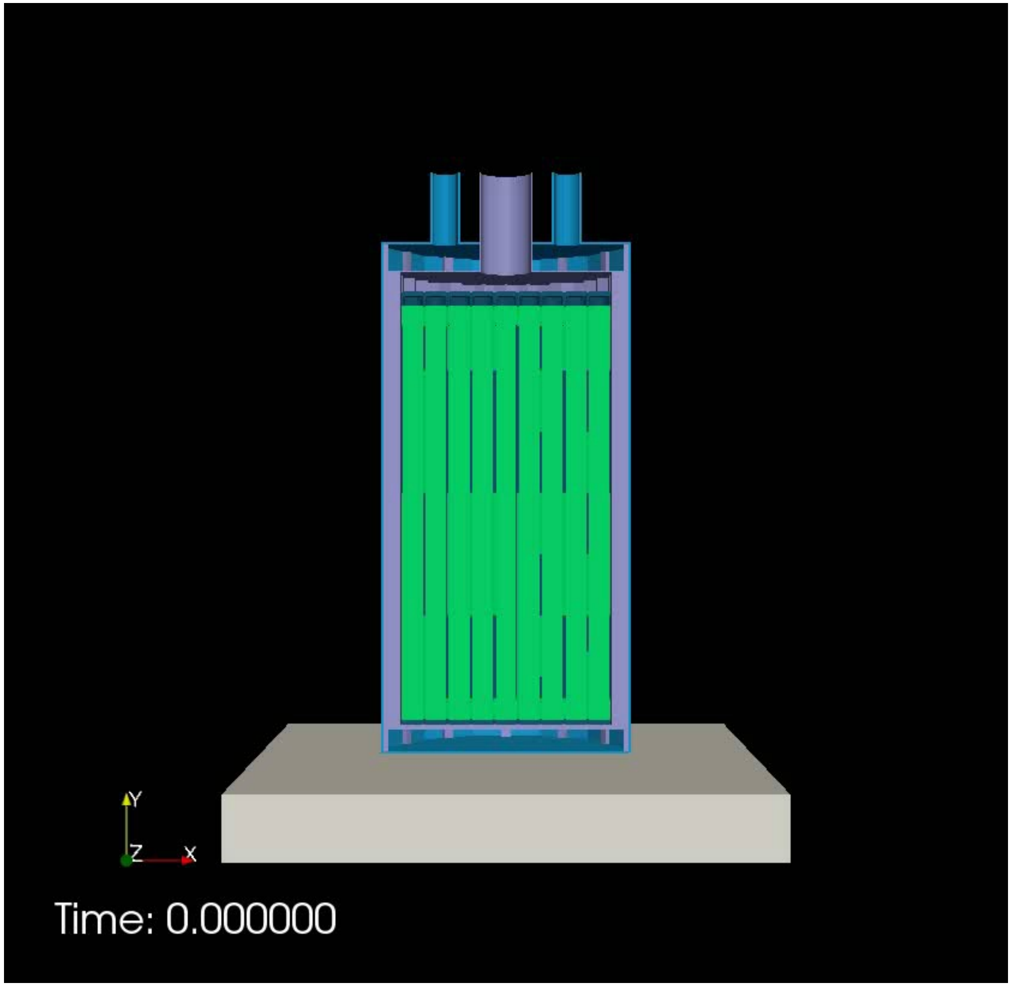
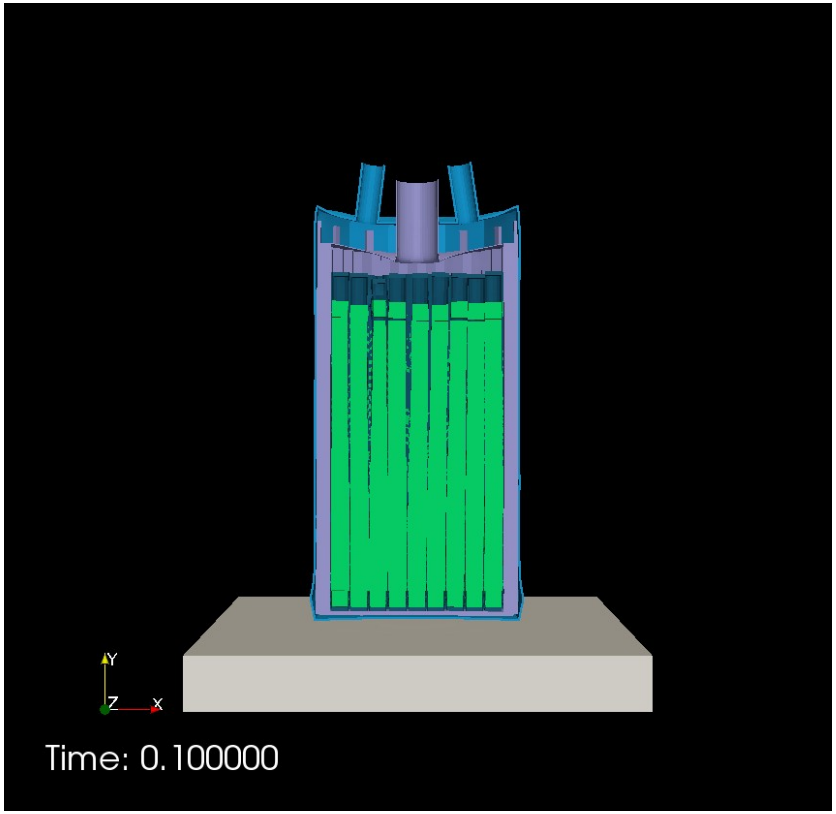
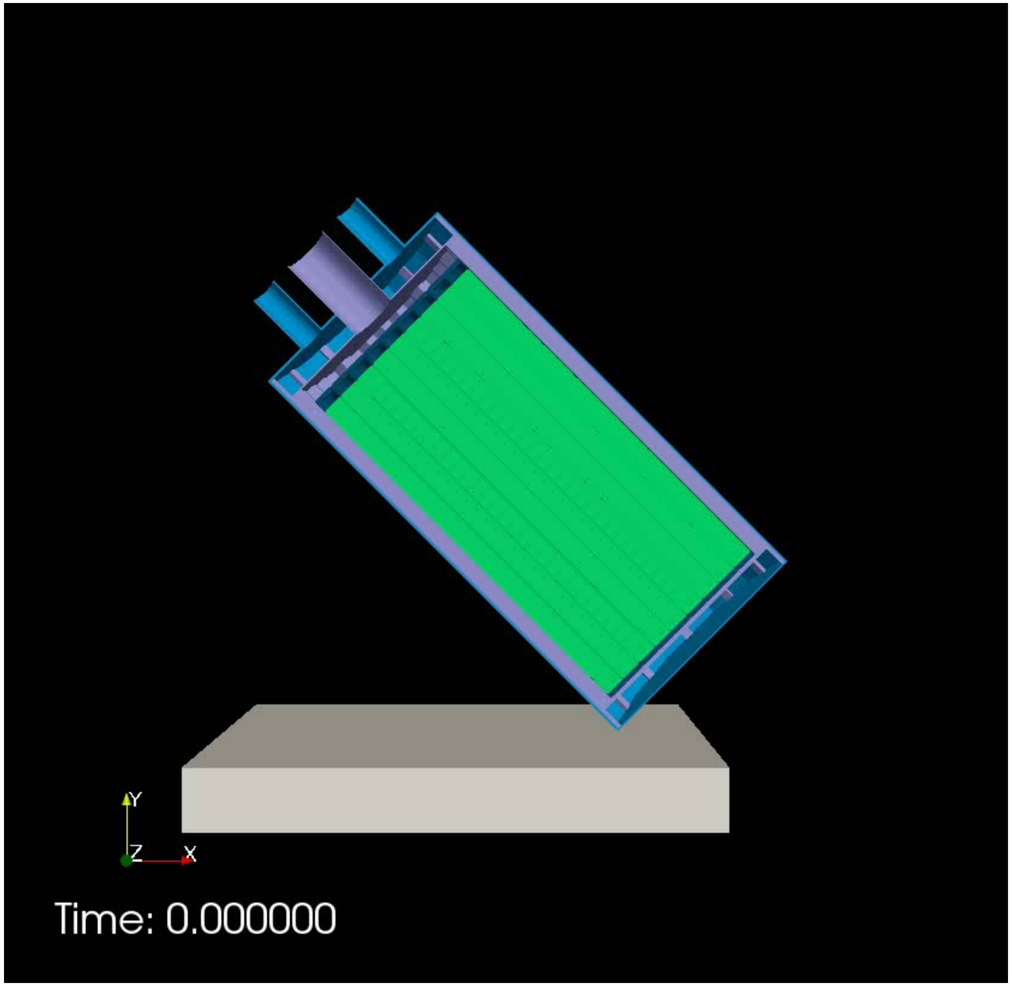
85-Pin Full-Scale Space Reactor Impact

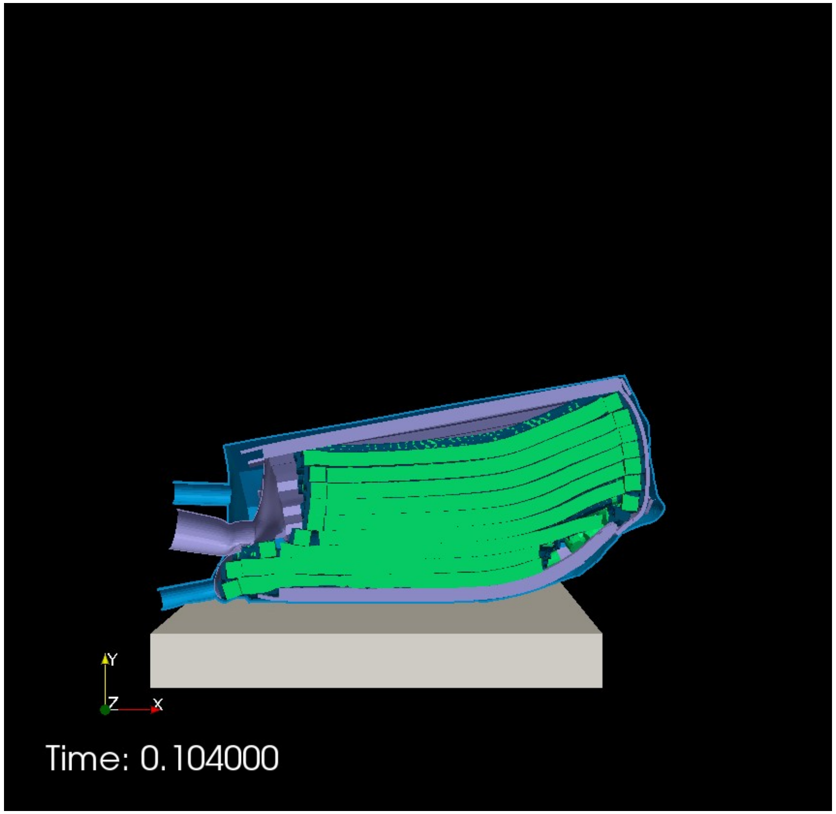




40 m/s, 0º on concrete

85-Pin Full-Scale Space Reactor Impact, 45°

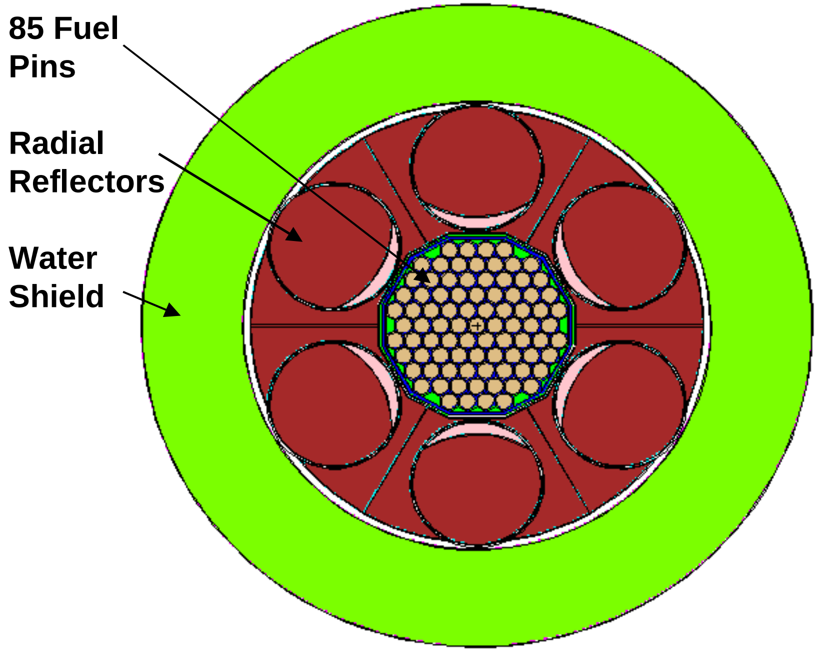




40 m/s on concrete

Reactivity Changes for Assumed Deformation

- Scoping studies were made of reactivity changes from assumed deformation
- Bottom half of all pins were expanded until they touched
- Pin lengths were reduced to keep the same total fuel mass
- Neutron Multiplication (k-eff) increased by roughly 5% ($7)
- Reactor stayed subcritical



85 pin reactor cross section

Approximation of a 40 m/s, 0°, impact on concrete; not the results of a DAG-MCNP run

MCNP Results for 85-pin Reactor Model

Status	Geometry (CD* position)	Surrounding Material	Keff (std dev)
Pre-Impact	Water Shield (0)	Void	1.02072 (0.00096)
Pre-Impact	Water Shield (180)	Void	0.86142 (0.00101)
Post-Impact	Water Shield (180)	Void	0.90915 (0.00076)
Post-Impact	Pressure Vessel (NA)	Water	0.88644 (0.00105)
Post-Impact	Pressure Vessel (NA)	Wet Sand	0.95541 (0.00098)
Post-Impact	Pressure Vessel (NA)	Liquid H_2	0.81910 (0.00092)

* Control Drum, 0 degrees is full out, 180 is full in

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